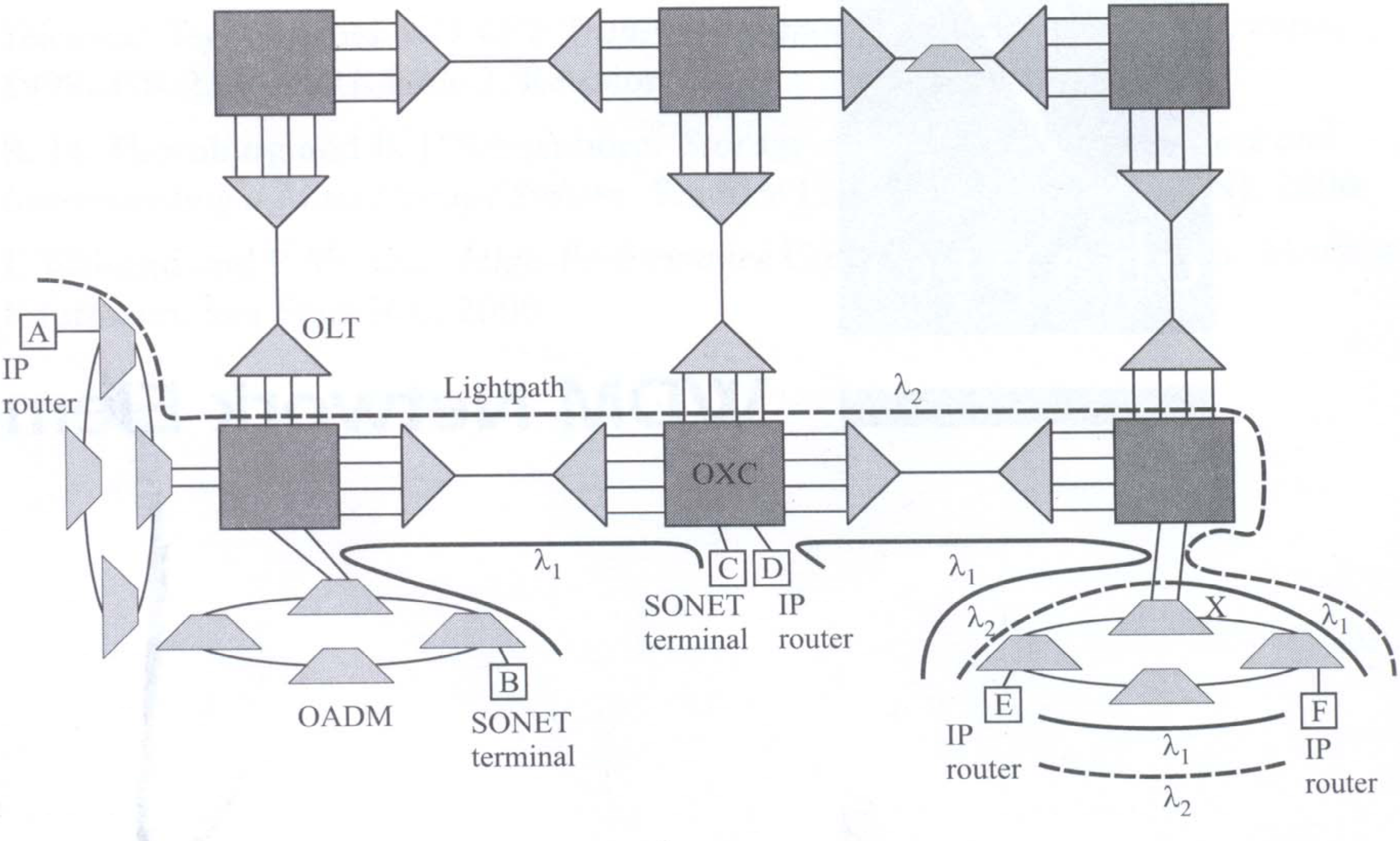
WDM Network Elements

- A lightpath consists of an optical channel, or wavelength, between two network nodes that is routed through multiple intermediate nodes.
- Intermediate nodes may switch and convert wavelengths.
- Networks may thus be thought of as wavelength-routing networks.
- Lightpaths are set up and taken down as dictated by the users of the network.
- Network consists of optical line terminals (OLTs), optical add/drop links.

WDM Network Elements

- OADMs, and OXCs may themselves incorporate optical amplifiers to make up for losses.
- As of this writing, OLTs are widely deployed, and OADMs are deployed to a lesser extent.
- OXCs are just beginning to be deployed.
- Architecture (Fig7.1) supports a variety of topologies, including ring and mesh topologies.
- OLTs multiplex multiple wavelengths into a single fiber and also demultiplex a composite WDM signal into individual wavelengths.



A
IP
router
OLT
Lightpath
λ2
OXC
λ1
C
D
SONET
terminal
IP
router
λ1
λ2
X
λ1
B
SONET
terminal
OADM
E
IP
router
λ1
λ2
F
IP
router

Figure: 7.1

WDM Network Elements

- OLTs are used at either end of a point-to-point link.
- OADMs are used at locations where some fraction of the wavelengths need to be terminated locally and others need to be routed to other destinations.
- Network provides lightpaths to its users, such as SONET boxes and IP Routers.
- Lightpath is carried on a wavelength between its source and destination but may get converted from one wavelength to another along the way.

WDM Network Elements

- They are typically deployed in linear or ring topologies.
- OXCs perform a similar function but on a much larger scale in terms of number of ports and wavelengths involved, and are deployed in mesh topologies or in order to interconnect multiple rings.
- The users (or clients) of this network are connected to the OLTs, OADMs, or OXCs.
- Network supports a variety of client types, such as IP routers, ATM switches, and SONET terminals and ADMs.

WDM Network Elements

- Each link can support a certain number of wavelengths.
- Number of wavelengths that can be supported depends on the component and transmission-imposed limitations.
- Several noteworthy features of this architecture:

Wavelength reuse

- Multiple lightpaths in the network can use the same wavelength, as long as they do not overlap on any link.
- This spatial reuse capability allows the network to support a large number of lightpaths using a limited number of wavelengths.

Wavelength Conversion

- Lightpaths may undergo wavelength conversion along their route.
- One such lightpath that uses wavelength $\lambda 2$ on link EX, gets converted to $\lambda 1$ at node X, and uses that wavelength on link X F.
- Wavelength conversion can improve the utilization of wavelengths inside the network.
- Wavelength conversion is also needed at the boundaries of the network to adapt signals from outside the network into a suitable wavelength for use inside the network.

Transparency

- Transparency refers to the fact that the lightpaths can carry data at a variety of bit rates, protocols, and so forth and can, in effect, be made protocol insensitive.
- This enables the optical layer to support a variety of higher layers concurrently.
- Lightpaths between pairs of SONET terminals, as well as between pairs of IP routers.
- These lightpaths could carry data at different bit rates and protocols.

Circuit switching.

- Lightpaths provided by the optical layer can be set up and taken down upon demand.
- These are analogous to setting up and taking down circuits in circuit-switched networks, except that the rate at which the setup and take-down actions occur is likely to be much slower than, say, the rate for telephone networks with voice circuits.
- In fact, today these lightpaths, once set up, remain in the network for months to years.
- Note that packet switching is not provided within the optical layer.

Circuit switching.

- The technology for optical packet switching is still fairly immature.
- It is left to the higher layer, for example, IP or ATM, to perform any packet-switching functions needed.

Survivability

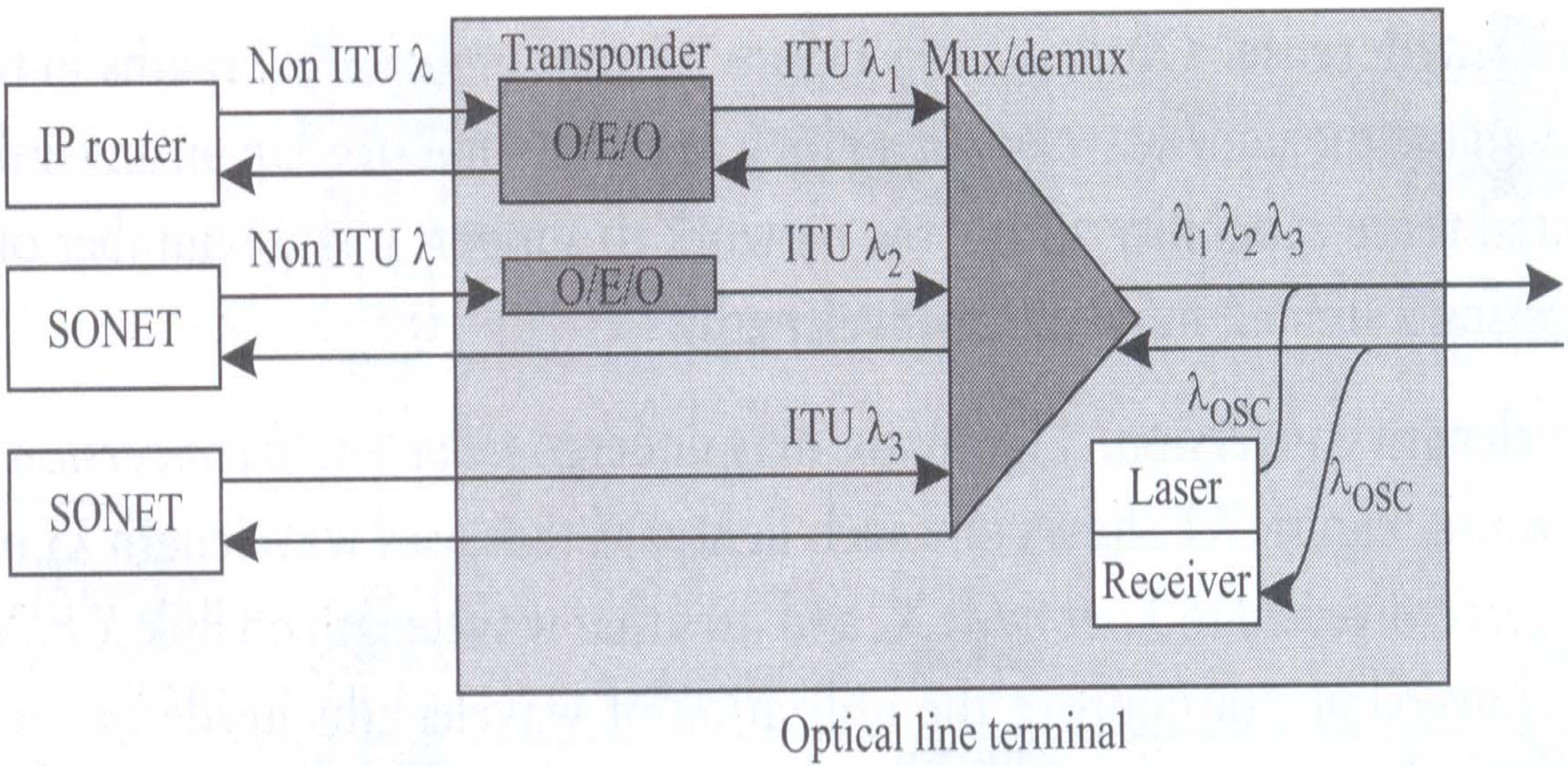
- Network can be configured such that, in the event of failures, lightpaths can be rerouted over alternative paths automatically.
- This provides a high degree of resilience in the network.

Ligthpath topology

- Lightpath topology is the graph consisting of the network nodes, with an edge between two nodes if there is a lightpath between them.
- Lightpath topology thus refers to the topology seen by the higher layers using the optical layer.
- IP network reside above the optical layer - the lightpaths look like links between IP routers.
- The Set of lightpaths can be tailored to meet the traffic requirements of the higher layers.

WDM Network Elements

- Block diagram of an optical line terminal is on next slide.
- The OLT has wavelength multiplexers and demultiplexers and adaptation devices called transmission over the WDM link and an incoming signal from the WDM link to a suitable signal toward the client.
- Transponders are not needed if the client equipment can directly send and receive signals compatible with the WDM link.
- OLT also terminates a separate optical supervisory channel (OSC) used on the fiber link.



Non ITU λ
Transponder
ITU λ1
Mux/demux
IP router
O/E/O
Non ITU λ
ITU λ2
λ1 λ2 λ3
SONET
O/E/O
λOSC
ITU λ3
SONET
Laser
λOSC
Receiver
Optical line terminal

Figure: 7.2

Optical Line Terminals

- OLTs are relatively simple network elements from an architectural perspective.
- They are used at either end of a point-to-point link to multiplex and demultiplex wavelengths.
- Three functional elements inside an OLT: transponders, wavelength multiplexers, and optionally, optical amplifiers.
- A transponder adapts the signal coming in from a client of the optical network into a signal suitable for use inside the optical network.

Optical Line Terminals

- Likewise, in the reverse direction, it adapts the signal from the optical network into a signal suitable for the client.
- Interface between the client and the distance and loss between the client and the transponder.
- The most common interface is the SONET/SDH short-reach (SR).
- Adaptation includes several functions.
- The signal may need to be converted into a wavelength that is suited for use inside the optical network.

Optical Line Terminals

- Wavelengths generated by the transponder typically conform to standards set by international Telecommunications Union (ITU) in the 1.55μm wavelength window.
- Incoming signal may be a 1.3μm signal.
- Transponder may add additional overhead for purposes of network management.
- It may also add forward error correction (FEC), particularly for signals at 10 Gb/s and higher rates.
- Transponder typically also monitors the bit error rate if the signal at the ingress and egress points in the network.

Optical Line Terminals

- Adaptation is typically done through an optical-to-electrical-to-optical (O/E/O) conversion.
- In some situations, it is possible to have the adaptation enabled only in the incoming direction and have the ITU wavelength in the other direction directly sent to the client equipment.
- In some other situations, we can avoid the use of transponders by having the adaptation function performed inside the client equipment that is using the optical network, such as a SONET network element.

Optical Line Terminals

- This reduces the cost and results in a more compact and power-efficient solution.
- WDM interface specification is proprietary to each WDM vendor, and there are no standards.
- Transponders typically constitute the bulk of the cost, footprint, and power consumption in an OLT.
- Therefore reducing the number of transponders helps minimize both the cost and the size of the equipment deployed.
- The signal coming out of a transponder is multiplexed with other signals at different wavelengths using a wavelength multiplexer onto a fiber.

Optical Line Terminals

- Fiber Bragg gratings, can be used for this purpose.
- In addition, an optical amplifier may be used to boost the signal power if needed.
- In the other direction, the WDM signal is amplified again, if needed, before it is sent through a demultiplexer that extracts the individual wavelengths.
- These wavelengths are again terminated in a transponder (if present) or directly in the client equipment.
- Finally, the OLT also terminates an optical supervisory channel (OSC).

Optical Line Terminals

- OSC is carried on a separate wavelength, different from the wavelengths carrying the actual traffic.
- It is used to monitor the performance of amplifiers along the link as well as for variety of other management functions..
- In figure 7.3, Amplifier uses multiple erbium gain stages and optionally includes dispersion compensators and OADMs between the gain stages.
- OSC is filtered at the input and terminated, and added back at the output.

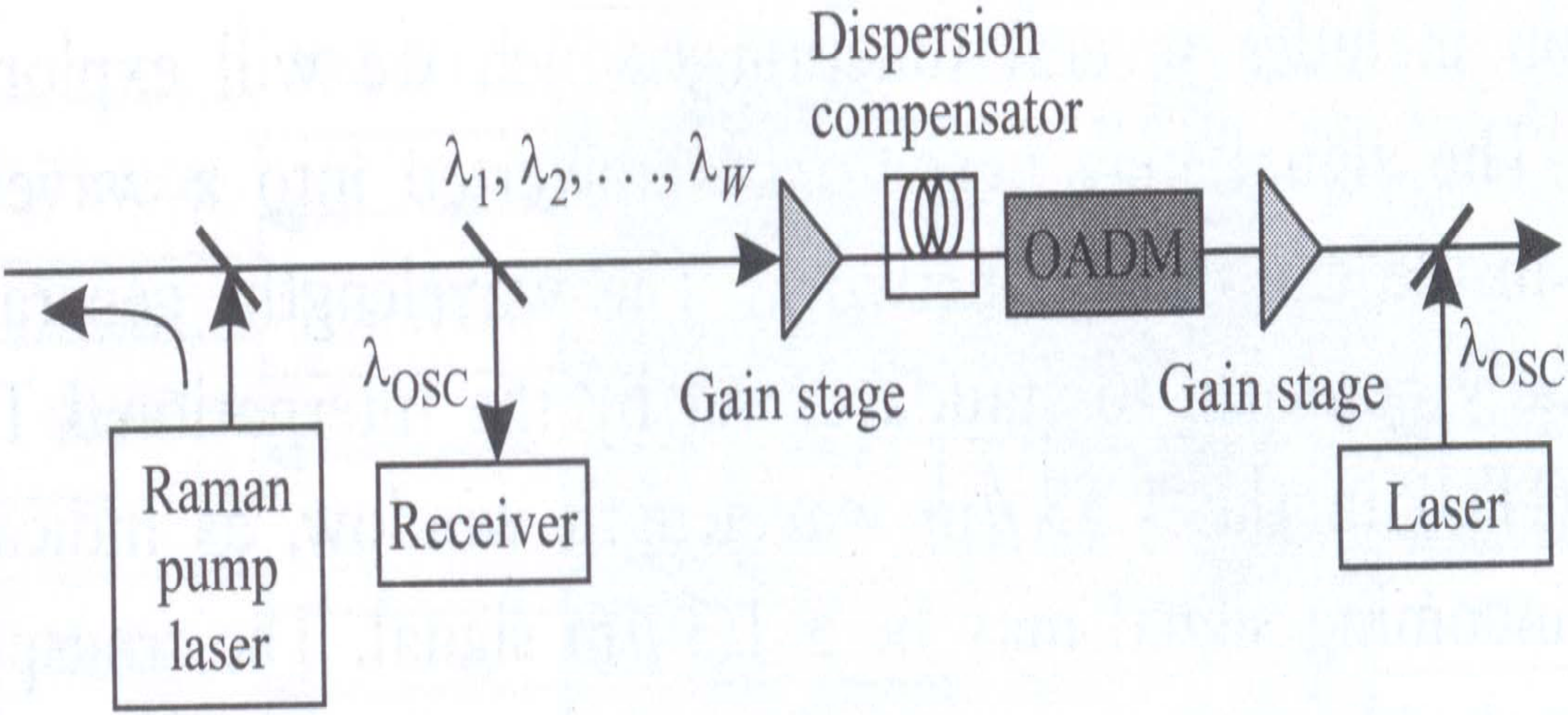

Dispersion
compensator
λ1, λ2, . . ., λW
OADM
λOSC
Gain stage
Gain stage
λOSC
Raman
pump
laser
Receiver
Laser

Figure: 7.3

Optical Line Amplifiers

- Optical line amplifiers are deployed in the middle of the optical fiber link at periodic intervals, typically 80-120 km.
- Basic elements is an erbium-doped fiber gain block.
- Typical amplifiers use two or more gain blocks in cascade, with so-called midstage access.
- This feature allows some lossy elements to be placed between the two amplifier stages without significantly impacting the overall noise figure of the amplifier.

Optical Line Amplifiers

- These elements include dispersion compensators to compensate for the chromatic dispersion accumulated along the link, and also the OADMs.
- The amplifiers also include automatic gain control and built-in performance monitoring of the signal.
- Optical supervisory channel is filtered at the input and terminated, and added back at the output.
- In a system using C-and L-bands, the bands are separated at the input to the amplifier and separate EDFAs are used for each band.

Optical Add/Drop Multiplexers

- Optical add/drop multiplexers (OADMs) provide a cost-effective means for handling passthrough traffic in both metro and long-haul networks.
- OADMs may be used at amplifier sites in long-haul networks but can also be used as stand-alone network elements, particularly in metro networks.
- In figure 7.4, A three node linear network example to illustrate the role of optical add/drop multiplexers.
- Three wavelengths are needed between nodes A and C, and one wavelength each between nodes A and B and between nodes B and C.

    7.4(a) A solution using point-to-point WDM systems.

    7.4(b) a solution using an optical add/drop multiplexer at node B.

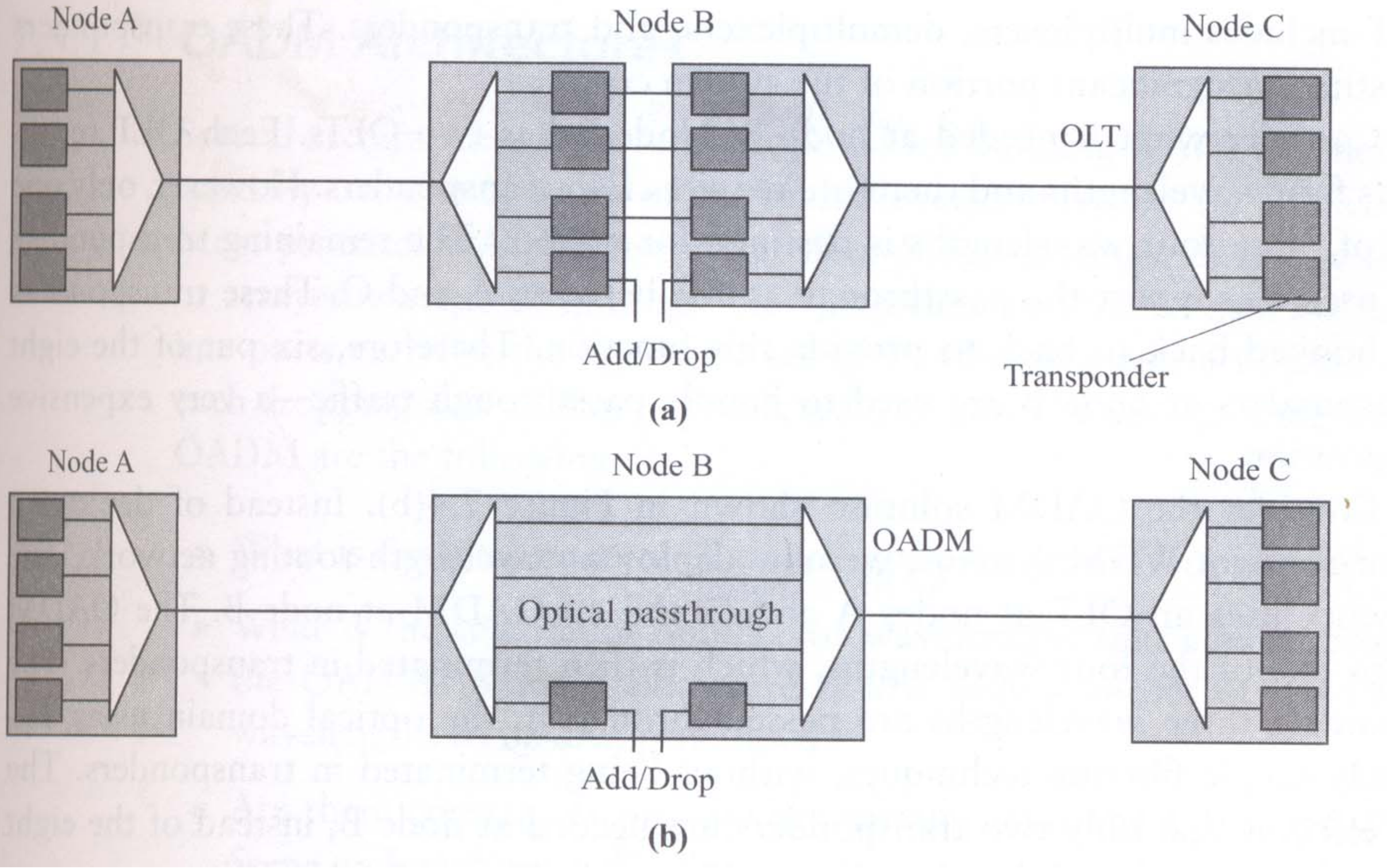

Node A
Node B
Node C
OLT
Add/Drop
Transponder
(a)
Node A
Node B
Node C
OADM
Optical passthrough
Add/Drop
(b)

Figure: 7.4

Optical Add/Drop Multiplexers

- To understand the benefits of OADMs, consider a network between three nodes, say, A,B, and C, with IP routers located at nodes A, B, C, and A and C.
- Based on the network topology, traffic between A and C passes through node B. for simplicity, we will assume full-duplex links and full-duplex connections.
- This is the case for most networks today.
- Actually consists of a pair of fibers carrying traffic in opposite directions.

Optical Add/Drop Multiplexers

- Suppose the traffic requirement is as follows: one wavelength between A and C.
- Now suppose we deploy point-to-point WDM systems to support this traffic demand.
- Two point-to-point systems are deployed, one between A and B and the other between B and C.
- Each point-to-point system uses an OLT at each of the link.
- OLT includes multiplexers, demultiplexers, and transponders.
- These transponders constitute a significant portion of the system cost.

Optical Add/Drop Multiplexers

- Consider what is needed at node B.
- Node B has two OLTs.
- Each OLT terminates four wavelengths and therefore requires four transponders.
- However, only one out of those four wavelengths is destined for node B.
- Remaining transponders are used to support the passthrough traffic between A and C.
- These transponders are hooked back to back to provide this function.
- Therefore, six out of the eight transponders at node B are used to handle passthrough traffic a very expensive proposition.

Optical Add/Drop Multiplexers

- Instead of deploying point-to-point WDM systems, we now deploy a wavelength-routing network.
- Network uses an OLT at nodes A and C and an OADM at node B.
- OADM drops one of the four wavelengths, which is then terminated in transponders.
- Remaining three wavelengths are passed through in the optical domain using relatively simple filtering techniques, without being terminated in transponders.

Optical Add/Drop Multiplexers

- Net effect is that only two transponders are needed at node B, instead of the eight transponders required for the solution shown in Figure 7.4(a).
- Represents a significant cost reduction.
- In typical carrier networks, the fraction of traffic that is to be passed through a node without requiring termination can be quite large at many of the network nodes
- OADMs perform a crucial function of passing through this traffic in a cost-effective manner.
- Physical layer engineering for networks is considerably more complex than that for point-to-point systems.

Optical Add/Drop Multiplexers

- OADMs are rather inflexible.
- They are, for the most part, static elements and do not allow in service selection under software control of what channels are dropped and passed through.
- Most practical OADMs use either fiber Bragg gratings, dielectric thin-film filters, or arrayed waveguide gratings.